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THE
PSYCHOLOGICAL BULLETIN

VESTIBULAR SENSATIONS AND THE MECHANISMS OF BALANCE

BY COLEMAN R. GRIFFITH
University of Illinois

The last survey of the experimental literature on the sensations, movements, and other bodily echoes of vestibular stimulation appeared in 1922 (37). This review of some seventeen hundred titles was occasioned by two facts. There was, on the one hand, the minor research crisis precipitated by the failure of current otological practice to meet some of the problems of balance raised by the aviation service during the war. The new researches begun at that time, taken in conjunction with a few long established prejudices, seemed to call for a thorough survey of the relevant historical material. There was, on the other hand, the permanent entrance into the experimental laboratory of the psychological (and behavior) problems concerned in the maintenance of bodily posture. Questions about static and dynamic equilibration have been in the physiological laboratories for a long time, and there have been, from the very first, a few supplementary psychological observations of an empirical nature; but for the most part these observations have remained accessory to the physiological and medical aspects of equilibration. The urgent demands of the aviation service have now passed away; but the psychological and physiological sciences have continued, in their own right, a steady attack on the questions that were left unanswered at the end of the war.

It is the purpose of the present review to bring the record of experimentation in this field up to date. We shall, however, leave out of account the medical and practical aspects of equilibration. The problems of vestibular function have always been, and still remain, of considerable concern to the otologist and to medical men

in general. This interest has continued unabated although many of the practitioners appear to be somewhat chastened by the exposures and discoveries of the five years following the researches of Bentley and Dunlap at the Mineola Research Laboratory (**56**). The large literature having to do with the diagnostic and remedial interests of the physician rather than with the experimental interests of the physiologist and psychologist is to be found in the medical rather than in the psychological journals. As we have said, we shall not attempt to pass this literature in review at the present time.

One further restriction has been placed upon the present survey. It is suggested by the rather sharp contrast that may be drawn between the methods and the problems that concern the American versus the Continental investigator. A great part of American research is functional in the sense that more attention has been paid to the nature of the bodily movements and adjustments which appear during and after vestibular excitation by the rotational method. This may be due to the fact that problems of equilibration came into American psychological laboratories by way of the aviation service. The Continental investigator, on the other hand, is still interested in the anatomical features of equilibration. He is still searching out the mechanisms, both cerebellar and muscular, that are responsible for the movements observed. The surgical and the galvanic methods have found great favor in this type of study, and as a consequence a large part of these studies are anatomical and strictly physiological rather than psychological or behavioristic (**18, 19**). We shall have to allow this difference in method and in the envisagement of vestibular problems to place a further limitation on the scope of the present review, since a survey of cerebellar tracts and of other neurological facts would tempt us too far away from our immediate task.

Taken in the large, recent research is characterized not so much by new discoveries and by new techniques as by a refinement of older methods and by a consolidation of information gained in the earlier and somewhat rougher ways. After it had been finally established by Griffith (**39**), Dodge (**15**), Holsopple (**41, 43**), and others, that Bentley and Dunlap (**56**) had been in the right in their dispute with the otologists, that is, afer it had been determined that the ocular and other organic effects of rotation are subject to the so-called "practice effect," so that these responses decrease and finally disappear under repeated turnings, it became necessary to specify in greater detail what the essential factors were in bringing about the reduction. Along with these studies has gone a further analysis and description

of the nature of the eye-movements excited by rotation, of the conditions adequate for their arousal, and of the central mechanisms involved in all types of compensatory adjustment and in the maintenance of bodily tonus. To be more specific, research on vestibular functions for the past seven years has concerned itself mainly with the following problems: (i) new descriptions of the experiences which attend vestibular stimulation; (ii) further demonstration of the effect of repeated turnings on the duration of nystagmus; (iii) further analysis of the conditions other than rotation which affect nystagmus; (iv) further studies on the nature of the central mechanisms, and (v) studies on the static rather than upon the dynamic mechanisms of posture.

I.

In a great many different ways attention has been called to the fact that the semicircular canals are the locus of receptor organs but not of sense organs. That is, the end organs in the canals do not mediate a specific sense quality of dizziness, or balance, or equilibrium. It is for this reason, perhaps, that scant attention has been paid to the experiential or phenomenological aspects of vestibular stimulation. Since the initial studies by the present writer (39) practically no further systematic attacks have been made on the somewhat unique pattern of experience commonly designated as dizziness or vertigo and neither have very many attempts been made introspectively to analyze the perceptions of movement involved in the maintenance of balance.

Dodge (16) has made a few observations on the latest time of the perception of movement and upon the relation between these perceptions and the bodily movements supporting them. He finds that there is no absolute relation between the cessation of nystagmus and cessation of the consciousness of rotation, a discrepancy that is held to be a serious stumbling block in the way of a thoroughgoing behaviorism. It appears, then, that the adequacy of consciousness is just as poor as the adequacy of some of the reflex movements. Habituation to rotation, so Dodge reports, is marked by a decrease in the clearness and complexity of the experience of rotation *pari passu* with decreases in bodily movement.

Travis and Dodge (68, 69, 70) have studied variability in perception when subjects are passively oscillated in simple harmonic motion at rigidly determined velocities and accelerations. Their results show

that the labyrinthine receptors function in the perception of, and reflex adjustment to, rotary and rectilinear changes in the velocity of the head. They could not discover, however, that the perception of motion could be localized. Sometimes the experience was related to the reflex adjustments of the organism and sometimes localized in the head itself. Vision and kinesthesis were found to play dominant rôles in the perception of the direction of bodily movement. When the body was free to move kinesthesis was at least ten times as effective as vestibular stimulation in the perception of passive rectilinear oscillation. Visual cues showed a still higher order of effectiveness (69, 70). In a later study, Travis (68) found that the perception of passive oscillation and intermittent rotation of the body was highly variable, suggesting a rhythmic pattern which was interpreted as implying rhythmic and arhythmic lowering and heightening of excitability or irritability in the neurovestibular system.

Fischer and Sommer (28) have studied the perceptions of movement among congenitally blind subjects stimulated by the caloric method. Reports from these subjects were compared with other reports from subjects who became blind in later life and with normal subjects. The writers concluded that the experience of rotation may be excited by the caloric method of stimulation quite independently of visual experiences; but there is inadequate analysis of the "experiences of rotation." In many other places there is much empirical observation on the phenomenological aspects of vestibular stimulation but there is still room for more critical studies.

II.

It is not necessary to do more than mention the papers which further confirm the reduction of nystagmus under repeated turnings. The papers already cited (Griffith, Dodge, and Holsopple) have been supported by all further research under a multiplicity of conditions. The matter has been tested more and more often among various animals and the same results have appeared. In short, no exceptions to the discovery that repeated turnings decreases nystagmus are at hand, and this discovery must now be taken as a solid *datum* in fact and method.

Maxwell and his students (58, 61) have found reduction to take place in the eye-movements of rabbits, and Detlefsen (12, 13, 14) has further confirmed it for white rats. Dunlap (21) reports the same observation when a caloric rather than a rotational stimulus is

used on rabbits. Moreover, rabbits adapted to a caloric stimulus failed to display nystagmus when rotated. The caloric stimulus had thus produced a certain adaptation to the rotational stimulus also. King (**44**) found a practice effect among squabs too small to fly.

The same type of reduction appears to hold in the case of head-nystagmus. In a series of experiments, the aim of which was to establish a " norm " of performance of adult pigeons without previous rotational experience as to amount and duration of the after-nystagmus following rotation of the body and to study the variability of this response after successive rotations taking place at a single experimental session, Fearing (**27**) found that post-rotational head-nystagmus in adult pigeons decreases as much as 30 per cent within ten trials of ten turns each. The duration of the head-nystagmus was decreased 25 per cent under the same conditions. A correlation of $r=0.82$ ($\pm$ 0.02) was found between head oscillations and the total duration of the head-nystagmus.

In a closer examination of the eye-movements which appear during and after rotation, Dodge (**16, 17**) has found that the saccadic eye-movements disappear first. That is, as he says, to be expected, since they issue from a higher center than do the reflex compensatory movements which are obviously vestibular in origin. The same thing was found to be true of the eye-movements due to small oscillations rather than to complete turnings.

The fact that the after-effects of rotation decrease under repeated turnings has had, so it appears, ample demonstration. All of the preceding studies either prove it anew or describe some condition under which the rate of change may be modified. It has not been made clear, however, as to the persistence of this " practice effect." Dodge (**15**) found that an interval of one week caused only a slight loss of the training effect. Griffith (**38**) found that it endured over a fairly long period of time. This was true in the sense that, after an interval of five years, the initial post-rotation nystagmus was much less than the original; only a few turnings were necessary to restore the original practice effect *in toto*. The same observation is suggested by Dunlap's studies (**21**) on the effect of caloric stimulation where rabbits were the subjects. As time goes on, and other subjects appear who have had a history in the laboratory are tested, this fact will receive, no doubt, further study and examination. In the case of prolonged rotation no other permanent effects than a tendency toward middle ear infection have been found. Gould (**36**) made a microscopic examination of the labyrinths of eleven albino rats

which had been subjected to long continued rotation in cages turning at 60 and at 90 r.p.m. No abnormalities of size, shape, or orientation of the labyrinth or of its parts was found to account for some of the abnormal reactions that often appear in subjects treated in this way.

III.

Among the conditions apart from rotation that are now known to affect the duration of nystagmus, two have received special attention. These are (i) the mechanical conditions of rotation and (ii) the position or posture of the head during rotation. Dunlap and Dorcus (22) were able to show that the rate of starting and stopping in all rotation experiments must be rigidly controlled. This had been a prime failure of almost all the earlier experiments. When after-nystagmus is measured from the moment the brake is applied to a rotation chair, the duration of the after-nystagmus appears to stand in direct proportion to the rate of stopping. The longer the process of retardation the longer the average nystagmus time. It is not, therefore, sheer violence of stimulus as in the quick stop that issues in a prolonged after-effect, but a less violent stimulus exerted over a longer period of time.

The position or posture of the head during rotation appears to have an equally profound effect upon the duration of nystagmus and upon the rate at which movement is reduced. Maxwell and two of his students (61) have shown that the reduction in nystagmus and in the number of eye-strokes takes place four times as fast when the head is free to move than when it is fixed. In another study, Maxwell (58) found that rotational as well as after-nystagmus was reduced, the former being reduced only 50 per cent, however, when the latter had disappeared. The subjects in these experiments were rabbits. Lumpkin (53) was able to confirm these observations and to insist that adaptation with head free versus head fixed presents two fundamentally different problems. These experimental results stand in contrast, therefore, to those gained by Dorcus (20), who found that, in human subjects, reduction takes place more quickly when the head is fixed than when it is free to move.

Other factors which have been noted are age, weight, condition of the muscles, and the previous history of the subjects. Detlefsen (12, 13) found that age and labyrinthine infection were important when white rats were subjects. He computed a negative correlation of $r = -0.38$ ($\pm$ 0.014) between after-nystagmus and age. He

was able to show that such factors as temperature, hunger, and excitement cause variation but he was not able to gain a quantitative measure of these factors. In the case of head-nystagmus, Fearing (**27**) is persuaded that weight, age, muscle tonus conditions, position of head, and previous environmental conditions of the animals have much to do with the duration of the movement.

Maxwell and Pilz (**60**) found that vision plays a considerable part both in acceleration and in post-rotational nystagmus. Rabbits rotated in the dark (without total adaptation) do not have so prolonged an after-nystagmus as those rotated in the light. Moreover, the rate of decrease with repeated turnings was found to be greater under the former than under the latter conditions. This result was suggested by earlier studies on pigeons, which have shown that nystagmus during actual rotation largely disappears when the field of vision is circumscribed by a gray cylinder. Laurens and Miles (**48**) also found that vision affected the duration of the nystagmus. The experiments were performed on frogs and rabbits, and consisted of the removal of a single labyrinth. Both acceleration (rotary) and post-rotational nystagnus were increased by the elimination of moving visual images.

In King's experiments on young squabs (**44**), head-free practice resulted in only a small decrease of head-nystagmus, while training with the head fixed resulted in a much greater decrease. Blinding appeared to decrease rotation-nystagmus but to increase after-nystagmus. The same condition favored practice effect on rotation-nystagmus but appeared to have little influence on post-rotation-nystagmus. Decerebration had no demonstrable effect on habituation to rotation-nystagmus but it did lessen the practice effect on after-nystagmus.

Most searching in technique and in envisagement of problems have been the studies of Dodge (**16, 17**) on thresholds of rotation and upon the adequacy of the reflex compensatory movements. The questions are: "What is the minimum rotation that the vestibular mechanism may be relied upon to detect? Under what circumstances does the vestibular mechanism function as an adequate control of locomotion? and How far may it be trained?" (17, p. 108). Training, as we have already seen, may go pretty far; but thresholds of rotation are not so easy to determine because of the technical difficulties incident to quantitative measures. Dodge reports, however, that the thresholds for rotation of rapid onset seems to be somewhere between one and two degrees per second, but a velocity of four

degrees per second is too slow to produce uniformly correct judgments of rotation.

The adequacy of reflex compensatory eye-movements has also attracted Dodge's attention (17). Dodge had already shown the "amazingly high level" of adequacy of plain coördinate compensation, but no such levels were found to obtain (save under restricted conditions) when compensation was initiated by the vestibule. Of particular interest was the relation between compensations elicited by the cortex as opposed to the basal ganglia when visual data conflicted with vestibular data. Dodge discovered that vestibular reflex deviation of the eyes precedes and initiates all compensatory eye-movements incident to rotation even when the eyes are open. Initial compensation is only approximately adequate to account for the actual speed of rotation. This reflex deviation of the eyes is then interrupted by cortical impulses, after which reflex control again becomes dominant. There is thus an alternation of control which takes place "almost mechanically" at lower speeds. "As the vestibular stimuli become most intense, *i.e.*, at greater speeds of rotation, with increasing difficulty of adequate visual pursuit, cortical control is established with increased hesitation. At a speed of one rotation in three seconds rivalry becomes conspicuous and the vestibular and visual controls were impaired" (p. 180). King (44) also found evidence that visual stimuli inhibit after-nystagmus by way of the cerebral hemispheres.

The number of eye-movements and other related responses to vestibular stimulation appear to depend also upon such general conditions as dementia precox and emotion. Claude and others (10) found a considerable diminution of labyrinthine excitability in dementia precox patients. Boenninghaus (8) states that the compensations which normally occur after unilateral injury to the vestibular mechanisms do not always appear under strong emotion.

Lorente de Nó (52) insists that variable and inconsistent patterns of nystagmus following extirpation of one labyrinth in dogs shows that the state of the whole nervous system is one of the factors influencing nystagmus. It is possible, however, that these inconsistent results may be attributed to the grossness of the surgical method in this type of study. The fact that as many as twenty-six "normal" types of nystagmus (24) have been distinguished suggests the richness of the rotational method where surgical methods may be uncertain.

Closely related to these studies is the work of Lorente de Nó (52)

on the reflexes of rotation and the eye-muscles. The innervation of the eye-muscles of rabbits were studied during and after various types of rotation. Evidence was found of close interaction between the otoliths (called sluggish receptors) and the canals (called quick receptors) in the production of patterns of ocular movement. The author found that the extent and duration of nystagmus in the different muscles varied with the position of the head. He found, too, that the horizontal canals are the most effective, especially when they are in their normal position. Some evidence was found in support of the contention that the horizontal canals are " movement " canals, while the vertical canals are " positional " organs.

IV.

Experimenters have come, at length, to the place where they can theorize about the causes of reduced nystagmus under repeated turnings. Present theories begin with a sharp distinction between rotation-nystagmus or acceleration-nystagnus and after-nystagmus. The first appears as a result of the initial change of acceleration, that is, as a result of the change from a stationary to a moving position (Holsopple). It is not apparent that rotation as such has any appreciable effect upon the mechanisms of equilibration. It is change of acceleration, or angular acceleration, either positive or negative, rather than sheer movement with zero acceleration, that is effective. Maxwell (**58**), as we have seen, found that rotational nystagmus as well as after-nystagmus is reduced with repeated turnings but not in the same proportion, for the former had been reduced only 50 per cent when the latter had completely disappeared.

In the second place, it has been discovered that under certain conditions there is an unequal reduction in post-rotation-nystagmus following turnings in a single direction. Dodge (**15**), for example, rotated subjects in one direction only and then at the end of the experiment turned his subjects in the other direction, with the result that about half the training in the first direction had been transferred to the second. Holsopple (**43**) repeated this experiment but found that repeated turnings in one direction, which decreased post-rotation for that direction, seemed to have little effect on the post-rotation for the opposite direction.

These conflicting observations then first led to further experimentation and then to the formulation of a theory to account for the unequal effects of rotation on the duration of after-nystagmus.

According to Holsopple (43) nystagmus will begin with an acceleration (either positive or negative) and will stop either because it has run its course or because it has been interrupted by a stimulus from the opposite side, as would happen when rotation is begun and then stopped before the after-effects of the original change in acceleration have had time to complete their course. Thus, Holsopple argues, nystagmus time will decrease by virtue of having frequently run to normal completion, and it is not reduced merely because of the frequent occurrence of its stimulus. Hence either type of nystagmus can be reduced by rotation in either direction, depending upon the distribution of time allotted to rotation and to rest intervals. That is, by controlling the time allotted to rotation and to rest, it is possible (i) to reduce the post-rotation nystagmus for the direction of repeated rotation, (ii) to reduce the post-rotation nystagmus for the direction opposite to that of the repeated turnings, or (iii) to produce no reduction effect. A similar conclusion was reached by Maxwell, Burke, and Reston (61).

There is still no confidence among investigators as to where nystagmus should be placed among the reflexes. The fact that it suffers diminution under practice appears to separate it from most of the other reflexes. On the contrary, the effects of vestibular stimulation do not appear to be like the other bodily movements that are so easily subject to the sort of practice that leads to a process of learning. Fearing's uncertainty is the uncertainty of the whole field. He says: "The present investigator has no theory to offer as to the neurological accompaniment of this modification of a reflex response. Whether the modification observed is permanent or temporary remains unsettled so far as the present data are concerned. The doctrine of the invariability of the reflex is in need of revision. It is suggested that not only labyrinthine reflexes but other reflexes may be subject to this type of functional modification. The curves obtained in the present instance closely approximate those obtained in the psychological laboratory with human and animal subjects, commonly called 'learning curves.' Whether this change with repeated performance is to be called habituation, practice, adaptation, tolerance or learning,—all of which have been suggested,—is a matter for further discussion and agreement" (27, p. 130).

Dodge (15) has gone at the matter more heroically. Since the compensatory eye reflexes are conditioned by activity in a part of the nervous system which stands relatively high on the primitive cerebrospinal axis, Dodge finds it not unreasonable to expect that "premoni-

tions of cortical developments" should appear. That is, one might expect to discover effects of repetition which "represent cortical learning processes in simpler configuration" (15, p. 30). But even if this is done, one cannot be too optimistic about it, first, because in learning some discrete reaction is consolidated, whereas here a reflex enters a pronounced refractory phase and is disestablished; and second, our traditional laws of memory and learning are supported by purely hypothetical constructs. It may be, therefore, that an understanding of the "practice effect" should suggest "a new attack on the neural problem of learning" (15, p. 31). One possibility is suggested by the fact that any learning involves the processes of inhibition as well as other processes; and there are times when this negative factor may become dominant. There is the possibility, then, that the "practice effect" may be found ministering to orthodox traditions of learning rather than that the orthodox traditions shall be brought to bear upon vestibular training.

On the physiological side evidence as to the real nature of the adequate stimulus for the semicircular canals continues to favor currents in the endolymph. The principal contribution to this phase of the problem appears to have been made by Leise (**49**, **50**, **51**) who succeeded in blocking off the effects of caloric stimulation so as to focalize cooling at different points of the inner ear (in areas as small as 3 sq. mm.). Slight decreases of temperature produce only horizontal nystagmus but further conduction resulting from still lower temperatures may affect the vertical canals as well. In this connection it is illuminating to note (**51**) that a position of the head can be found (lateral 30°) in which cold rinsing of the ear does not produce nystagmus (Leise). Steinhausen (**67**) has found a way of making the physical occurrences in the ampullae amenable to direct observation. Here is strong support for the theory that currents in the endolymph are at least one adequate form of stimulus for the end organs of equilibration.

When both ears are irrigated at once, a position of the head can be found which, like that described by Leise, may be called the "indifference point." Fischer and Veits (**32**) have made careful studies of this indifference point and of the planes of maximal stimulation. In the median plane a maximum is found at 90° and in the sagittal plane at 45°. These facts are related to and stand in support of the endolymph current theory, according to the authors.

V.

The physiologist has much preferred the surgical method of exciting the vestibular mechanism. Some of the earliest observations were made by this method and a review of the literature seems to suggest that no small part of the disagreement that obtains between workers in this field is due to the nature of the method, that is, to uncertainty about the extent of the surgical damage, rather than to any lack of uniformity in the mechanisms themselves. There has been, however, a tremendous methodological improvement over Ewald and the others who brought labyrinthine studies into vogue and descriptions of changes of tonus and types of movement elicited by the surgical and other methods is becoming more and more objective.

Benjamins and Huizinga (6), for example, have made new studies on muscle tonus of different bodily members which are immeasurably better than their predecessors. Their method of attaching writing points to the wings of pigeons and thus gaining an objective measure of tonus is very similar to the method by which Maxwell (59) gained records of eye-movements. Dozens of other studies on the relation between tonus and labyrinthine stimulation have appeared, many of them using this same technique. Most of these studies, however, fall outside of the scope of the present review.

Davis and Pollock (11) have used the method of decerebration to study the tone of neck and limb muscles under various types of intra-oral destruction of the labyrinth on one and on both sides. Groebbels (40), in particular, has made elaborate studies of posture and tonus in pigeons under various types of labyrinthine stimulation. He has succeeded in gaining objective measures of changes in tonus and has described these changes as they stand related to each of the three ampullae. He was able to make operative findings agree with the results gained by galvanic stimulation, his attention being directed upon the tonus of head, neck, wings, tail and legs.

Maxwell and Huddleston (59) have succeeded in describing in a graphic way the relations that obtain between individual ampullae of the horizontal canals and individual eye muscles. Stimulation of a horizontal ampulla evokes a strong contraction of the homolateral rectus internus and of the contralateral rectus externus and at the same time a weak contraction of the superior and inferior recti and of the two oblique muscles. It appeared that the latter four muscles acted as fixation muscles so as to secure rotation of the eyeball around

its vertical axis. Reference should be made, perhaps, to Dohlman (**18, 19**) who has reviewed the recent literature on this group of problems, especially as it stands related to the caloric and galvanic methods of stimulation.

VI.

From the very first, two functions have been ascribed to the vestibular portion of the inner ear, viz., the static and the dynamic functions. The latter have captured the interest of most investigators but the former have recently come into the psychological laboratory, principally at the hand of Miles and some of his students. The physiological aspects of static posture have been reviewed quite adequately by Langworthy (**47**).

The long line of investigations concerned with the static equilibrium of the body have been bound up at various times with the studies on equilibratory mechanics, with the hygiene of the so-called "attention-position," with clinical studies on the amount of sway as a type of neuromuscular coördination, and now it is being taken as a test of motor ability or motor control. To this end Miles (**62**) has devised an instrument called the ataximeter. This instrument is designed to measure sway in terms of millimeters and without the errors and difficulties of the graphic methods used by Vierordt, Luciani, Hinsdale and others. Fearing (**25, 26**) has found that static equilibrium, as represented by bodily sway, is subject to practice in much the same manner as is post-rotational nystagmus. It is, moreover, subject to changes in attention. Distraction of attention (120 beats per minute from a Wundt sound-hammer) decreased sway in sixty subjects (**25**). These results were confirmed by Brammer (**9**) who used airplane pilots as subjects; but it was not observed that flying contributed to this practice effect since nonflyers equalled pilots in tests of station. Neither was Brammer able to show that practice by other means had any relation to flying aptitude. It was observed, however, that "poor" flyers showed a greater difference in static equilibrium with eyes closed as against eyes open than did "good" flyers.

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THE PSYCHOLOGY OF TASTE AND SMELL
STATUS OF 1929

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In the thirteen years which have elapsed since the publication of *Der Geruch* (15) interest in the psychology of smell has centered in the problem of classification, and especially in the scheme symbolized by Henning's smell-prism. The present writer (10, 11) has already twice summarized the doctrines of Henning. By this time they are too well known to require further exposition, although some readers may need to be reminded that he distinguishes six classes of odors—flowery, fruity, putrid, spicy, resinous, and burnt—and claims that each class passes over into every other through transition smells. The writer, who published in 1922 her last summary of work in smell and taste, wishes especially to discuss the experimental criticisms of Henning which have since appeared. First, however, it should be mentioned that in 1924 Henning published a second edition of *Der Geruch* (15). In this edition, he banishes the prism to a late chapter, but he does not reply very satisfactorily to his critics. Nevertheless, it should be remembered not only that Henning has given an enormous impulse to the study of smell, but also that he has contributed to many phases of its psychology beside that of qualitative arrangement.

Dimmick (7, 8) (1922 and 1927), MacDonald (20) (1922), Findley (9) (1924) and Bentley (2) (1926) have all reported experiments by which they sought to secure for the prism the statistical evidence which Henning notoriously fails to supply. The outstanding result of all these experiments may perhaps be indicated by saying that not half the evidence necessary to substantiate the prism has been found.

The historical connection of the five investigations may be sketched as follows: Dimmick and MacDonald worked almost simultaneously but without coöperation. Dimmick, who by his choice of scents "prejudiced his investigation" in Henning's favor, reports some real evidence for the prism. MacDonald, however, concluded on the basis of paired-comparison experiments that his

findings correspond with Henning's only to an extent which might be indicated by a product-moments correlation between .30 and .40. MacDonald criticizes Henning's chemistry and also criticizes the prism on "logical" as well as on "factual" grounds. (To the present writer, geometrical fault-finding seems superfluous. No such figure can show everything. Even the idolized color-pyramid does not show that true red and true green are *not* complementary.) Findley adopted MacDonald's methods but used only scents which Dimmick's observers and Henning classified in much the same way. In spite of this concession to Henning, she found as little evidence for the prism as did MacDonald. Both Findley and MacDonald stress the inconsistency of their observers. Both required the use of every comparison-smell with every pair of six smells typifying Henning's classes. Some of the variability of the observers may be explained (the writer believes) by the necessity of comparing given odors with pairs of smells excessively unlike them. This consideration may have induced Bentley to confine his list of scents to the flowery-fruity-spicy region. At any rate, Bentley's results seem more favorable to Henning than are those of MacDonald and Findley. But his chief contribution is his insistence on the necessity for greater refinement in experimental method and in particular upon the need for careful instructions to subjects and for the standardization of their criteria in judgment. Dimmick acted upon these suggestions (or else upon similar ideas of his own). He has devised noteworthy apparatus for controlling such matters as time intervals and intensity of stimulation. He also gave his observers clear-cut instructions, and he analyzed in an illuminating manner the criteria by which they judged resemblances between odors. His observers actually became more self-consistent with practice. But as to the prism, he appears to be completely disillusioned.

The last link (known to the writer) in the study of smell classification has nothing to do with Henning. This is the significant contribution of Crocker and Henderson (**4**), chemists in the perfume industry. Boring (**3**) has made an exposition of their theory. They claim that there are four types of smells—fragrant, acid, burnt, and caprylic—but that most odors are of mixed type. They classify each smell by determining its position upon a nine-point scale of resemblance to each of four standards. Thus every odor tested is described by a combination of four digits. A classification of twenty-five odors by the two investigators and two unpractised observers shows surprising agreement.

Little space remains for discussion of problems other than classification. Kenneth (16, 17) has made elaborate studies of the "affect" and the associations aroused by odors. Perhaps his most important findings are the great constancy of affective judgments of odors and the dependence of affect on both the intrinsic quality and the associative supplement of a smell. Glaze (12, 13), employing four different observers, has shown that sensitivity to odors is increased during a long fast. Liggett(19) has demonstrated that to the white rat the sense of smell is of relatively little value. Kolmer (18) has collected anatomical data which tend to show that the sense is less developed in the anthropoid apes than it is in ourselves.

In the domain of taste, the most important investigation of recent years is that of Allen (1), who with various collaborators has been studying the stimulation of different receptors with an interrupted electric current. He believes that the sensitiveness of a receptor can be measured by the length of the interval betwen stimuli which succeed one another just rapidly enough to produce continuous sensation. The *longer* the interval, the more sensitive the organ. The electric current produced a sour taste by electrolysis of the saliva. Allen argues from his data that every taste stimulus sets up in some degree all four of the principal tastes. It is impossible to explain here his statistical procedure.

Goldschmidt (14) has shown by histological examination of twenty dead children and by inspection of eighty living children ranging in age from one week to thirteen years that the distribution of taste papillae does *not* vary in a regular way with age but is a matter of individual difference. Crosland (5, 6) has studied taste sensitivity in two cases of traumatic anosmia and has found no compensatory increase. Both subjects, however, were well able to distinguish foods by secondary cues.

The writer has had space to summarize only those investigations which seem to her most important. Her judgment of relative importance may be faulty.

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CUTANEOUS AND KINAESTHETIC SPACE[1]

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1. *Perception of form and size*

Zigler and Northup (**40**) find that tactual form, produced by a cardboard form applied to the forearm with vision excluded, is not as definitely apprehended as tactual pressure. The latter is invariably perceived, while the tactual form is not definitely given in a considerable percentages of cases, and is not apprehended at all in some instances. Form discrimination is minimal in cases of pressure totally devoid of outline and maximal where the complete contour of a figure-form is given at all points in terms of the tactual impression. Geometrical figures must have a main dimension of 12 to 15 mm. to give rise to definite tactual form impressions on the middle of the forearm. The optimal main dimension for the mid-forearm, by the author's method of stimulation, is 20 mm. In another study Zigler and Barrett (**41**) applied figures (square, hexagon, diamond, equilateral and right-angle triangles) with a pressure of 500 gms. on the palm, ball of the thumb, and volar surface of the forearm. Three forms of figure (solid, outlined, and pointed) cut out of rubber were used. The clearest discriminations were obtained from outlined, solid, and pointed figures in the order named. The main supplementary cues for the perception of point figures are "tactual tied-imagery" and "visual imagery." The most adequate perceptions are furnished by the thumb, palm, and forearm in the order given. Acute angle forms were perceived more frequently than obtuse or right angle ones. The following stages may be distinguished during the gradual rise of perception: (a) A stage of shapeless pressure, (b) an intermediate stage in which one or two salient features of the form acquire definiteness of clearness, and (c) the final stage in which the outline is clearly and completely given. DeGowin and Dimmick (**6**) performed an experiment in order to obtain "descriptions of the spatial patterns of several touch perceptions whose stimuli have definite visual patterns and to determine

[1] This paper includes the literature on Cutaneous and Kinaesthetic Space appearing during the last four years.

whether, as in the case of vision, tied images play any part in these images." The forms used were a line, circle, equilateral triangle, and square. The results show that purely tactual perceptions do not naturally take on the meaning of form that correspond with our visual geometrical forms. When such tactual patterns of form are built up, it is only by the addition of other elements, usually visual. In spite of their lack of resemblance to the visual forms of the stimuli the tactual patterns are stable and readily recognized. Tied images similar to those in vision and audition, play a large part under the right conditions in filling out the tactual patterns from incomplete stimuli. Rosenbloom (**29**) sought to determine whether or not the principles, found by the *Gestalt* school to govern visual perceptions, are equally applicable to tactual perceptions. Seven figures (circles, squares, triangles), 3 complete and 4 incomplete, were applied to the palm of the hand. After stimulation the O's were asked to draw or describe the figures and to indicate the degree of certainty of their response. It was concluded that: (a) closed figures are more easily perceived than open ones; (b) the circle and the triangle have the best figure qualities of the seven figures used; (c) the open figures tend to be perceived as closed; and (d) the figure has properties of its own and influences its component parts. Ueno (**33**) reports experiments on perceptual judgment of space bisection. He worked with school children, soldiers, college students, adults, and blind people. Bisection, lines, a pair of dots, angles, and a glass rod were presented vertically as well as horizontally. The lines were drawn on white cards, 2 mm. wide and 20, 40, 60, 80, and 100 mm. long. The dots were .5 mm. in diameter, and the pairs were separated by distances of 20, 40, 60, 80, 100 mm. The angles were made by two lines .2 mm. wide and 68 mm. long. Angles of 30, 45, 60, and 90 degrees were used. The glass rod was 8 mm. in diameter and 550 mm. long. A band was fixed at each end and a third band in the center could be slid along the rod at will. Each subject gave ten judgments on the perception of each of these stimuli. The average of these judgments was the individual score from which the mean constant and the variable errors of a group was computed. The following results were obtained: There were great individual differences in regard to age and sex. The variable errors did not change much with reference to the intensity of the stimulus. The right halves of lines and dots in horizontal positions and the upper halves of lines and dots in vertical positions showed a constant error of overestimation. When the vertex of the angle

was above, the left halves were overestimated; when the vertex was on the left, the lower halves were similarly judged. The bisection of the glass rod by means of muscular and tactile cues verified Weber's law. There were no important differences between blind and seeing subjects. The constant and variable errors could be decreased by practice, but the direction of constant errors tended to remain stable. Warden and Flynn (**36**) found that the apparent size of a series of colored cartons placed side by side does not depend upon the intrinsic quality or upon the immediate contrast effect of their color, but upon their specific serial arrangement. The color-weight illusion was found to be greater than the color-size illusion.

2. Perception of length and distance

Using a solid pasteboard plate of constant width but varying in length from 4 to 20 mm. (4, 8, 12, 16, and 20), Faucault (**8**) studied the perception of length on the three phalanges of the index finger. Immediately after noting the length of the stimulus the subjects were required to indicate on a standard scale the varying lengths which seemed to them to approximate most closely the tactual experience. It was found that the per cent of error decreased as the distances were increased. The diminution of error was rapid at first, then slow with a tendency to remain constant. In comparison, the second phalange yielded fewer errors of discrimination than the first and the third. Similar experiments were carried out on the dorsal and palmar sides of the finger. These showed a diminution of errors in passing from the dorsal to the palmar side. The greater accuracy of the second phalanx and of the palmar side of the skin is attributed to the greater density of sense organs in these regions. Some individuals increased their ability to discriminate by movement of the stimulus while others did not. On the basis of these experiments and certain theoretical considerations the author concludes that the perception of length on the skin "comprises a fusion or assimilation, with the ensemble of sensations, of an image which recapitulates past perceptions." This results in individual differences of ability to discriminate length by means of the skin. Kuroda (**20**) reports a study of distance perception in a two-year-old child. The child was placed before a table, 90 cm. long, 70 cm. wide, 41 cm. high, and made to get candy placed at various points around the edge of the top. Under these conditions the child chose the shorter route 10 times out of 12 trials. In order to determine to what extent orientation played a part in the discrimination, a desk was placed at one

of the shortest sides of the table thereby extending the circuit 136 cm. Under these conditions the child chose the longer route three times and the shorter route twice. Next a box was added to the farther end of the annexed desk extending the circuit 84 cm. Under these conditions the child chose the shorter route 3 times and longer route once. The ambiguous results under the first and last conditions show that orientation is not an indispensable factor in the child's discrimination of distance. Kiesow (17) used the method of minimal changes to make comparisons of linear distance. In 1,400 trials with one subject, lines differing in length were compared. Weber's law was found to hold under conditions outlined in the article.

3. *Perception of movement and speed*

Michotte and Galli (23) measured the discriminatory threshold for the change of position in passive movements of the subject's arms. The apparatus consisted of two handles which moved along the side of the ruler and could be stopped at any position by the experimenter. The subject who was blindfolded kept his hands on the handles and judged the displacements undergone. From these experiments the authors deduce the theory that space may be phenomenally present in a kinaesthetic form. This is in opposition to current conceptions that the space between the two hands does not correspond to a sensitive surface, and that only the points which limit this space can be perceived. The authors find a strong analogy between visual and kinaesthetic perception of space. Hulin (14) experiments on the illusion of apparent movement on the skin of the forearm with a modified Benussi kinohapt. From seven subjects 13,500 judgments were obtained on the effect of two tactual stimuli presented at temporal intervals ranging from simultaneity to 300σ and spatial intervals varying from 5 to 150 mm. with a duration of 150σ and a weight of 4 gm. Of the judgments taken, 29.7 per cent represented experiences of some sort of apparent movement in the tactual field. The optimal time relationship between the two stimuli was 75σ. The various spatial separations were found to give the appearance of movement with uniform frequency. The perceptual complex was shown to involve four variable factors, perseveration, pressure irradiation, visual imagery, and kinaesthesis. Pellegrini and Ponzo (27) report interesting studies on judging the speed of an automobile in motion. The speed was judged by the subject while sitting in the back seat of an automobile. The judgments of errors are less during constant motion than while slowing

down or speeding up. Speeding up results in overestimation whereas slowing down results in underestimation of speed. Another study on the perception of changes of speed while riding in an automobile is reported by Kunze (19). The 34 subjects serving in this experiment were also tested in nine performances believed to be components of the general practical speed judgments, acoustical, optical, and vibrational components, reaction time, skill, etc. Only the auditory test results (judgment of changes in sounds) correlated significantly with the practical speed judgments.

4. *Perception of load*

Weber (37) discovers that the kinaesthetic perception of intervals of space and time may be altered by the presence of "fields of force" or load. A given distance under load is phenomenally equivalent to a smaller time interval under less load. There are indications that load equally affects the perception of area and the phenomenally straight line, consequently perhaps also the degree of angle. In another experiment Weber and Dallenbach (38) sought to obtain a more complete "geometry" of the "muscle sense." The effect of load on judgment of area, angle, and arc was studied by the method of constant stimulus-differences. Stimulus-area of 5 different sizes were used, the middle one of which served in every case as the standard. The perimeter of the square area was traced by the blindfolded subject with a stylus which could be weighted in three different amounts. Twenty-five comparisons were made of the standard and of every variable by every subject under each of the 6 experimental conditions. The changes which were produced in the limens by the changes in the size of the outline traced led to the following generalizations: "(1) A given area sensed under load appears to be phenomenally enlarged. (2) A given angle traversed under load appears to be phenomenally more acute, *i.e.*, smaller. (3) A given arc traversed under load appears to be phenomenally more sharply curved, *i.e.*, to be a curve of smaller radius. (4) As a load is increased, critical points are reached where the results due to the load are reversed." These results are believed to suggest tentatively that the geometry of the muscle is hyperbolic.

5. *Perception of stimuli of different qualities*

Malamud (21), in an attempt to determine the tactual stimulus limens, applied to the volar surface of the arm two hard rubber points, followed by two sharp metallic points, and vice versa. From

the thresholds obtained the author summarizes as follows: " (1) Two spatial contents objectively equal but limited by stimuli of different qualities are perceived as unequal; (2) that such contents between the pain-bearing stimuli are perceived as smaller than between tactile; (3) these qualities must be cutaneous in type, in other words, cutaneous sensations; for other qualities which are of geometrical value do not seem to exert such an influence."

6. Localization of temperature

In an introspective analysis of the experience of heat Burnett and Dallenbach (3) find that heat is variously localized. At times it appears " surfacy " and on the skin, at other times " voluminous " and in the arm. One observer localized it outside of the body. Strughold (32) finds that the threshold of cold is much lower in the sclera and the cornea, where the end-bulbs of Krause lie close to the surface, than elsewhere where the bulbs lie deeper. In a very careful survey of temperature-discrimination within the range not involving pain or extreme discomfort, with special reference to the validity of Weber's law, Culler (5) reports that at skin temperature the sensitivity of the left hand is more than twice as great as that for the right hand. Helmuth and Lueg (12) question the existence of simultaneous contrast in the field of temperature sensations. Temperature sensations are believed to be confined to the area which is directly stimulated.

7. Localization of pressure, pain and tickle

Kiesow (17) raises the question whether or not Weber's law holds if only a single tactile organ is stimulated. He finds that the law holds also under such conditions and that the attempt to explain the results on the basis of variations in intensity of the stimulus must be considered futile. Friedman (9) repeated some of Czermak's experiments on the two-point threshold to determine the spatial threshold in children. The work was done on 48 normal and 48 subnormal children, aged ten to fifteen years. A specially constructed apparatus (Spearman's aesthesiometer was found inadequate) was used for stimulation. In normal children the results showed a decrease in spatial sensitivity up to the age of twelve years, after which there was an increase. This increase is believed to be more dependent upon intellectual than upon anatomico-physiological factors. In abnormal children there was a tendency for spatial sensitivity to increase with mental age.

Mayer (22) used both Weber's and Volkmann's method of localizing pain and pressure on an area of 50 cm.² on the volar surface of the left lower arm. A correct localization was more easily achieved after pressure than after pain. In 1911, Ponzo had found just the opposite. von Skramlik (34), in a theoretical paper, agrees with Mayer who did her work under his direction. Kiesow (16) repeated Goldscheider's experiment on the cornea and conjunctiva bulbi in order to settle a difference of opinion as to the arousal of a pure sensation of cutaneous pain. The experiments were performed with small stimulus rods about 6 cm. long. On the point-end of the rod was twisted a little flake of sterilized cotton that ran out into a fine point. The author's results favor von Frey's theory, and lead to the conclusion that separate physiological mechanisms must be assumed for the sensation of pain and touch, and that the conditions of their arousal are different. Nafe (24) finds that the qualities of felt (cutaneous and kinaesthetic) experiences are analyzable patterns. Felt experiences are, qualitatively regarded, patterns of brightness (or sharpness) of greater or less complexity. These experiences may be localized. In another study on dermal sensitivity with special reference to qualities of tickle and itch, Nafe (25) finds no evidence for the existence of specific tickle and itch spots. The theory of double stimulation in the production of tickle is suggested.

8. *Clinical observations*

Holmes (13) finds that in cortical lesions those forms of sensation which give us information as to the position in space of parts of the body, the spatial relation of different parts of our limbs and of their movement, and the ability to recognize objects by handling them are more affected than cutaneous sensitivity. Lesions of the sensory area of one hemisphere result in disturbances of sensation which are always limited to the opposite side of the body and may extend over the whole of the side, or may be limited to a limb or a portion of a limb. Wilson (39) reports that "dysaesthesia" (including apparently spontaneous disturbances of sensations which patients describe as "burning," "coldness," "wetness," "numbness," "deadness," "tingling," "pricking," "sensation of something moving," etc.) sometimes has a neural origin, while under other conditions a vascular or sympathetic vascular origin underlies the awareness of these tactile, painful, and thermal dysaesthesias.

9. *Synaesthesis*

Dallenbach (4) reports a case of synaesthesis of "pressury" cold hitherto undescribed. The subject's cold spots were of two kinds, those that gave the usual experiences, and those that gave secondary experiences localized in and around the teeth and cheeks. These latter spots occurred upon all spots of the body which were investigated, though with varying frequency. The secondary experiences are described as light, transient, and pressury in quality and are always localized on the side of the body stimulated. In view of the fact that the observer has a synaesthetic inheritance this case is believed to lend evidence to the hereditary theory of synaesthesis.

10. *Illusions*

Sharp (30) describes a rather novel tactual-visual illusion. The individual brings his two hands before his eyes, palms facing him, with the index fingers touching end to end. Holding the hands in this position from 20 to 30 cm. in front of the eyes the subject fixates a more distant point in such a way that he sees both of the fingers and the point. By drawing the fingers slightly apart the subject experiences the weird illusion of seeing the first joint of either one of the fingers floating in the air. It no longer seems to have any connection with the rest of the body, either visually or tactually. Gatti (10) reports an illusion in the kinaesthetic-tactual field similar to Zöllner's optical illusion.

11. *Theoretical*

After reviewing the various theories of local signature, Peterson (28) states his own theory in terms of orientation tendencies. He enumerates the following advantages in "conceiving local signature merely as orientation tendency instead of some mysterious guidance of action by assumed sensory signs or as some sort of reference to location by these signs": (a) The problems of spatial orientation become subject to experimental investigation of an objective nature. (b) The question of consciousness has no relevancy and need not enter into the experimentation or interpretation of spatially discriminative behavior. (c) No other theory of local signs accounts for the changes in the sensory nerves affected by the stimulation and in the proprioceptive fibers involved in the relevant movements, on the one hand, and changes in the motor nerves connected with the relevant effectors, on the other. (d) Differences between the nativists and empiricists become at once resolvable.

(e) The interminable controversies as to whether sensations have extension inherent in themselves or whether space can be built up by association of non-extensible mind-stuff become useless and even ridiculous. (f) Local signature and perception become only special problems in the special field of learning and are subject to objective experimental investigation. Gemelli (11) points out that while the Gestalt psychologist, by his attack upon the atomistic concept of the structuralist, has given new life to the study of perception, his denial of the possibility of analyzing perception into its constituents is untenable. Gemelli believes that a functional analysis of perception is possible. Perception itself is for him the organization of elements of sensorial origin into a whole to which we attribute a meaning. In harmony with this theory he posits six laws of perception: The law of least effort; the relative functional autonomy of perceptual elements; the functional unification of all elements of perception; the definite character of perception; rectification of sensory data and constancy of the intuitive organism; and the finality of the intuitive organism and of the significance of the "objects" of perception. The author finds these theoretical considerations supported by experiments in his laboratory. Besides a visual and a tactual space von Uexkull and Roesen (35) discover an "active" space within which our movements occur. As measured by arm movement, the shortest discriminable distance in this active directional space is about 2 cm. in each direction. The extent of this distance is registered by the resistance of the antagonistic muscles. Active space is made of a tridimensional network (stellen), held in a sensible coordination system extending from right to left, forward and backward, etc., independent of the position of the head and fixed for the individual. The necessity for the agreement of the co-ordination of visual space and active space results in nystagmus. The movement-signs are not to be identified with muscle sensations, but are of central origin. Reasoning from a series of experiments involving careful introspective analysis of the failure of perception in the sentient surfaces, Bose (1) reaches a thesis that perception is an illusion due to the influence of "active attitudes." He posits a law of localization which suggests that the localizing capacity of any part of the skin varies inversely with its aesthesiometric index. Delaunay (7) gives an account of the genetic development of visual and combined visual and kinaesthetic perception in the child. Parsons (26) attempts to build up a whole system of space perception upon Head's classification of sensibility. He prefers, however, to

substitute the term "dyscritic" for Head's protopathic sensibility. From a consideration of the comparative anatomy of vertebrates, he finds that the primitive apparatus of the tactile sense can be recognized from amphioxus to man. Stopford (31) discusses his clinical observations of sensation following section and suture of a peripheral nerve, and finds that the recovery of the cutaneous and deep sensation occurs in two stages. It is believed that two exactly comparable systems exist in both cutaneous and deep sensibility—one composed of elements of sensation concerned with protection, and the other with discrimination. It is not practicable to isolate the sensation of the skin from that of the deeper tissues. The existence of the two systems is explained by reference to the functions of the thalamus and the sensory cortex, together with a recognition of the disturbances of the intraneural patterns which are known to result from the operation of nerve suture. The central explanation accounts for all the observed facts for the normal sensibility of the glans penis and is also in accord with our knowledge of the evolution of the nervous system.

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SYNESTHESIA

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Anschütz (1) has made a detailed study of the synesthetic experiences of three artists. The article contains many drawings in color and in black and white, which were made by the subjects, and which show the colors and shapes that accompany the subjects' medical experiences. The author discusses at some length his psychophysiological theory of synesthesia. As he does not believe that there can be any direct connection between auditory and visual paths or centers, he postulates a theory of inner vision (inneren Sehens). It is difficult to interpret this term without knowing the author's concept of mind, but the equally vague term "higher mental process" is probably a sufficiently close translation. At the end of the paper there is a suggestion that synesthetic images may be the explanation for the visions often seen in occult experiences.

Anschütz (2) has also made a thorough analysis of the colored hearing of a blind subject, which in subsequent articles he refers to as the case of Dörken. The first part of the paper is devoted to an investigation of the colors and hues reported by the subject. Data and curves are given regarding the brightness, saturation, hue, etc. In the second part are presented more objective records, such as the relation of absolute pitch to hue. He concludes that many laws of synesthetic vision are to the smallest detail identical with ordinary vision.

Mahling (8) has written a detailed historical and critical treatise upon the problem of chromesthesia. He has also presented a long bibliography in two parts, the first dealing with the specific problems of colored hearing, and the second with the more general problems of color and tone. The bibliography is arranged in both alphabetical and chronological order.

Argelander (3) has made an extensive experimental study of chromesthesia, with emphasis upon the exact control of the tones and colors. The subjects were instructed after hearing the tone to select the synesthetic color from a series of colors placed before them. The experimenter included under colored hearing not only cases where

the observers imaged the color, but also where they were reminded of the color, but could describe it only with difficulty. As one would expect, the author found a certain lack of constancy and agreement. A number of problems were investigated, such as the relation of the tone to brightness, the reverse relation of a tone imaged to a seen color, the connection of colors with vowels, vowel pitch with brightness, vowel color with tone color, and colors with musical chords. A comparison was also given of the author's results with those of other investigators. Argelander undoubtedly did not know of Mahling's work, for a large part of the paper is devoted to a history of the problem and methods, and an account of the different theories of colored hearing, and the facts of visual sensations which might bear upon these theories. There is also a bibliography of 456 articles. As these two papers contain good histories of the problem and extensive bibliographies, they will be of great value to anyone experimenting in the field of synesthesia.

Wheeler and Cutsforth (10) have continued their investigations of the functioning of the synesthetic imagery of a blind subject. As in a previous paper, they have compared the results of the introspective report of the subject upon his method of concept building with those obtained by Fisher (*Psychol. Monog.* 21, 1916) upon normal subjects. Nonsense figures of clay were placed successively upon the observer's hand, and he reported upon the process of building a concept of these figures. The authors confirm their former results that synesthesia is not functionally an unusual process in the mental equipment of the subject, but is employed, as a rule, in both perception and conception. They again confirm Fisher's conclusion that meaning did not accrue to an imageless content but rather to imagery, at least in the case of this subject. As in a previous paper, they lay more stress on the kinesthetic factors in concept building than did Fisher.

Dallenbach (4) has described a case of a new form of synesthesia. The subject felt light, transient, pressure sensations in and around the teeth and cheeks when certain cold spots were stimulated. These "toothy" cold spots were located on all parts of the body on which experiments were performed. As the subject's mother also had a type of synesthesia, the author believes that the results support the theory of the inheritance of synesthesia.

Mayer-Gross (9) has sketched briefly some of the recent work on synesthesia, and then has described the synesthetic effect produced by mescal on normally nonsynesthetic subjects. The synes-

thesia was between audition, vision, and touch. Most of the secondary sensations were visual, though frequently touch sensations were aroused by visual and auditory stimulation. The author believes that these synesthetic phenomena under mescal will be helpful in explaining certain hallucinations in schizophrenic patients, and may also aid in determining the physiological processes underlying synesthesia.

W. Jaensch (7) has described his brother's, E. R. Jaensch's, classification of synesthesia in three classes: feeling, perceptual, and sensational synesthesia. He believes the quasi-visual experience of the " feeling-synesthetic " is similar to certain experiences of a hallucinatory character of the schizophrenic, and may explain the latter.

Hein (6) performed a series of experiments upon supposedly nonsynesthetic observes to determine if there was any consistency in the arrangement of colors in relation to tone. He later found that some of the observers were synesthetic. Notwithstanding the difficulty of evaluating the data, the author believes the results bear upon the problem of the development of color vision, and upon color nomenclature. According to the author, synesthesia seems also related to the problem of eidetic imagery. A mathematical treatment of the results revealed a law regarding the arrangement of the colors in relation to musical pitch. This arrangement seemed to throw light upon the inner relationship of the colors. The law seemed to hold only for nonsynesthetic and musically naïve synesthetic observers. The results of the musically gifted synesthetic observers follow another law.

Dauffenbach (5) has emphasized the importance of the relation of color to music. He has called attention to this relation in the music of famous composers, and has quoted a number of critics on the subject. He believes that it would be difficult to explain this relation on the basis of physics or physiology, and concludes that it is an association through the congruity of emotional responses. He does not refer directly to synesthesia in this article.

A number of articles have been written recently on the use of color in connection with music, but their review would take us beyond the scope of this report.

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